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NASA Program Apollo Working Paper No. 1160

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PREDICTION OF SOLAR PROTON DOSES IN THE APOLLO COMMAND MODULE AND LEM

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

February 15, 1965

ERRATA

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APOLLO COMMAND MODULE AND LEM

Dated February 15, 1965

Please make the following changes to page 2 of the working paper sent to your office.

chgd.
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LR

1. Paragraph 2, line 7 - change ".2391BeV" to ".2391 BV"

2. Paragraph 4, line 4 - change ".4448 BeV" to ".4448 BV"

3. Paragraph 4, line 5 - change ".2391 BeV" to ".2391 BV"

After these changes have been made, insert this Errata Sheet between the cover and approval page of your working paper.

March 10, 1965

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PREDICTION OF SOLAR PROTON DOSES IN THE APOLLO COMMAND MODULE AND LEM

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PREDICTION OF SOLAR PROTON DOSES IN THE APOLLO

COMMAND MODULE AND LEM

By Terence M. Vinson and Manuel D. Lopez

ABSTRACT

A method of predicting the solar proton dose inside the Apollo Command Module and LEM for various stay times in each vehicle is discussed. Using analytical expressions to obtain the time dependent flux for 54 recorded proton events, a computer program generates probability distributions of dose for various missions. From these distributions, curves of dose as a function of stay time for each vehicle are constructed.

INTRODUCTION

In a previous NASA TN by Modisette, Vinson, and Hardy (ref. 1), a method of determining the solar proton environment for missions of from one week to two years was discussed. In this method, the time-integrated fluxes of the 54 largest recorded events in the upper half of the last solar cycle were used as input data. A computer program was devised which calculated the total proton flux encountered during all possible missions of the desired length. The proton events were treated as "spikes" of flux; that is, the time-integrated flux for an event was assumed to be encountered in a single day. The total encountered fluxes were assumed to fit the normal probability distribution. Probability distributions of encountered flux were made up for each mission length, and from these, curves of flux as a function of mission length at certain probability levels were obtained.

This approach is valid for missions of the order of a week or longer, but for missions which are shorter than the actual duration of an event, a more sophisticated technique is necessary.

SOLAR PROTON DOSE ANALYSIS

General Method

The method described in reference 1 can be modified so that it can be used to predict doses for "missions", or stay times, which are of the order of a few hours long. Instead of considering every day in the six-year period covered by the data as the beginning of a mission, every hour of each day is so considered. A computer program then calculates the total flux encountered during each mission and the flux is converted to dose. The program then generates a probability distribution of doses encountered for that particular stay time.

Input Data

It was necessary in this analysis to describe as accurately as possible the time history of each proton event considered. To facilitate calculating hourly doses from the proton events, analytical expressions for proton flux were sought which reasonably filled available data. The rise time, event duration, peak and time-integrated intensities, as determined analytically, were required to match those of actual events at a rigidity of .2391 ~~BeV~~ BV (30 MeV).

The expression used to determine particle flux as a function of time t and rigidity P is:

$$F(P,t) = At^{\frac{n}{4}-1} \exp\left[-BPt^{n} - Ct^{-n}\right] \tag{1}$$

The constants, A, B, C, n, are determined from the analytical fit for each proton event. The time-integrated flux, $\int F(P,t)dt$, is proportional to $e^{-d\sqrt{P}}$ where d is a constant, and in most cases a value for d can be found such that there is a favorable agreement with the time-integrated proton fluxes as given by Webber (ref. 2).

A computer program was written which evaluates the constants A, B, C, and n from proton event data. $F(P,t)$ was then evaluated on an hourly basis giving the characteristic spectrum slope P_o and the intensities for rigidities greater than 0, .1366, .2391, and .4448 ~~BeV~~ BV. The hourly P_o and the flux for P greater than .2391 ~~BeV~~ BV were then used to calculate the corresponding dose rates. The dose rate calculations used normalized proton dose versus P_o relationships for the

command module and LEM as calculated by Hardy (ref. 3). For practical purposes, the dose rate calculated for a particular hour was considered to be the total dose for that hour.

Analysis of Results

The object of this study was to obtain probability distributions of the doses encountered during various stay times in the command module and the LEM. From these distributions, curves of dose versus stay time at various probability levels can be constructed. The distribution of dose received in the LEM is of greater interest because the LEM is a lightly shielded vehicle and it is to be expected that most of the dose will be received either in the LEM or on the lunar surface in the space suit.

The probability that a solar proton dose will be greater than D rads is given by the following equation which assumes that the doses are normally distributed:

$$P(z) = \frac{1}{\sqrt{2\pi}} \int_z^\infty e^{-z^2/2} \, dz \qquad (2)$$

where

$$z = \frac{\log D - \mu_L}{\sigma_L}$$

μ_L = mean of dose distribution for mission length L

σ_L = standard deviation of dose distribution for mission length L

For a given mission length, the probability P_e of encountering a dose of any size is given by:

$$P_e = \frac{\text{number missions which encounter a dose}}{\text{total number missions}} \qquad (3)$$

The probability of encountering a dose greater than D is therefore given by:

$$P_D = P_e \cdot P(z) \qquad (4)$$

P_e is a constant for a given mission length. An arbitrary value such as .01, .005, or .001 can be assigned to P_D, so that equation (4) can be solved for $P(z)$ and hence D can be obtained.

Figure 1 and 2 show the probability distributions of skin dose for stay times in the LEM of 24 and 48 hours. Figures 3, 4, and 5 show the distributions for stay times in the command module from 48 hours to two weeks. The straight lines in the figures were drawn by means of a normal fit using the mean and standard deviation of each set of data points. The data appear to fit a normal distribution reasonably well, except for the longer missions in the command module. This may be due in part to the manner in which the data were grouped. As in reference (1), the doses obtained were grouped according to the length of the mission in order to avoid redundancy in the large number of data points obtained. Actually, the averages of the groups of doses rather than the doses themselves are plotted. This, of course, tends to make the distribution more nearly normal.

Figures 6 and 7 show skin dose as function of time in the command module and LEM for three probability levels. From these curves one can predict the dose for a combination of time spent in both vehicles. For example, suppose an astronaut spent 72 hours in the command module, then 24 hours in the LEM, then 72 hours in the command module. For each stay time, what would the maximum dose be with probability .01? From figures 6 and 7 the following numbers are obtained:

72 hours in the command module	14 rads
24 hours in the LEM	165 rads
72 hours in the command module	14 rads
	193 rads

For each of the above stay times, the probability is 1.0 - .01 = .99 that the given dose will not be exceeded. The probability of not exceeding the dose during all three times taken in sequence is $.99^3 = .97$. Therefore, the probability of exceeding 193 rads for this sequence of stay times is 1.00 - .97 = .03.

This analysis is subject to possible error from three important sources. These are (1) the dose calculations for the two spacecraft, (2) the expressions used to generate the time-dependent fluxes for each event, and (3) the assumption that the doses are normally distributed. The second source of error is probably the most serious. Although no claim is made for the accuracy of the expressions used, they are probably the best that could be obtained, given the limited amount of data available on the fluxes and spectra of the actual events.

SUMMARY AND CONCLUSIONS

The following table shows a comparison of some of the results obtained in this study to some results obtained by an alternate method.

COMPARISON OF TWO METHODS OF DOSE PREDICTION

Command module stay time, hours	.01 probable dose, rads		Factor difference
	Method A	Method B	
48	31.5	7.8	4.03
100	42	21	2.00
140	44	33	1.33

LEM stay time, hours	.01 probable dose, rads		Factor difference
	Method A	Method B	
6	9	47	5.22
25	190	170	1.12
50	430	318	1.35
60	500	374	1.34
70	550	430	1.28

In method A, the integrated flux of a .01 probable event as determined in reference 1 was filled to a model time-variant spectrum suggested by Bailey (ref. 4). The dose calculations were performed by Hardy (ref. 3). Under method B are listed .01 probable doses as calculated by the method of this paper.

The doses obtained by method B are consistently lower than those obtained by method A with the exception of the six-hour dose in the LEM. The reason method A gives a lower dose in this case is probably because this method calculates the accumulated dose as a function of time after onset of the event, and in six hours the event has not reached its peak intensity. Method B, on the other hand, gives the .01 probable dose as obtained from the distribution of all six-hour doses, regardless of what point in the duration of an event they may occur.

In general, method A would be expected to give higher doses except for very short times, and the data in the table support this. The reason for this is that method A is based on a model event which has an integrated flux greater than any actual event ever recorded. This event had an arbitrary duration of 150 hours, which would cause the flux at any particular time to be unusually high. Method B uses models of actual events, and in most of these events the duration is 225 hours. In most cases, therefore, the intensities will be lower than those used in method A. Considering these factors, the agreement between the two methods is not bad. One may surmise that if the duration of the model event of method A had been longer, the agreement with method B would be better.

At present, this analysis is limited to dosage from solar protons. It does not include the effects of alpha particles, which are believed to be present in large events in numbers approximately equal to those of the protons. The input data can be changed to include alpha doses without too much difficulty. The dose will then be calculated in REM to take into account the different relative biological effectiveness of protons and alphas.

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2. Webber, W. R.: An Evaluation of the Radiation Hazard Due to Solar Particle Events. Boeing Company, D2-90469, December 1963.

3. Hardy, A. C.: Manned Spacecraft Center, Houston, Texas, private communication.

4. Bailey, D. K.: Time Variations of the Energy Spectrum of Solar Cosmic Rays in Relation to the Radiation Hazard in Space. Journal of Geophysical Researth, 67:1, January 1962, p. 391.

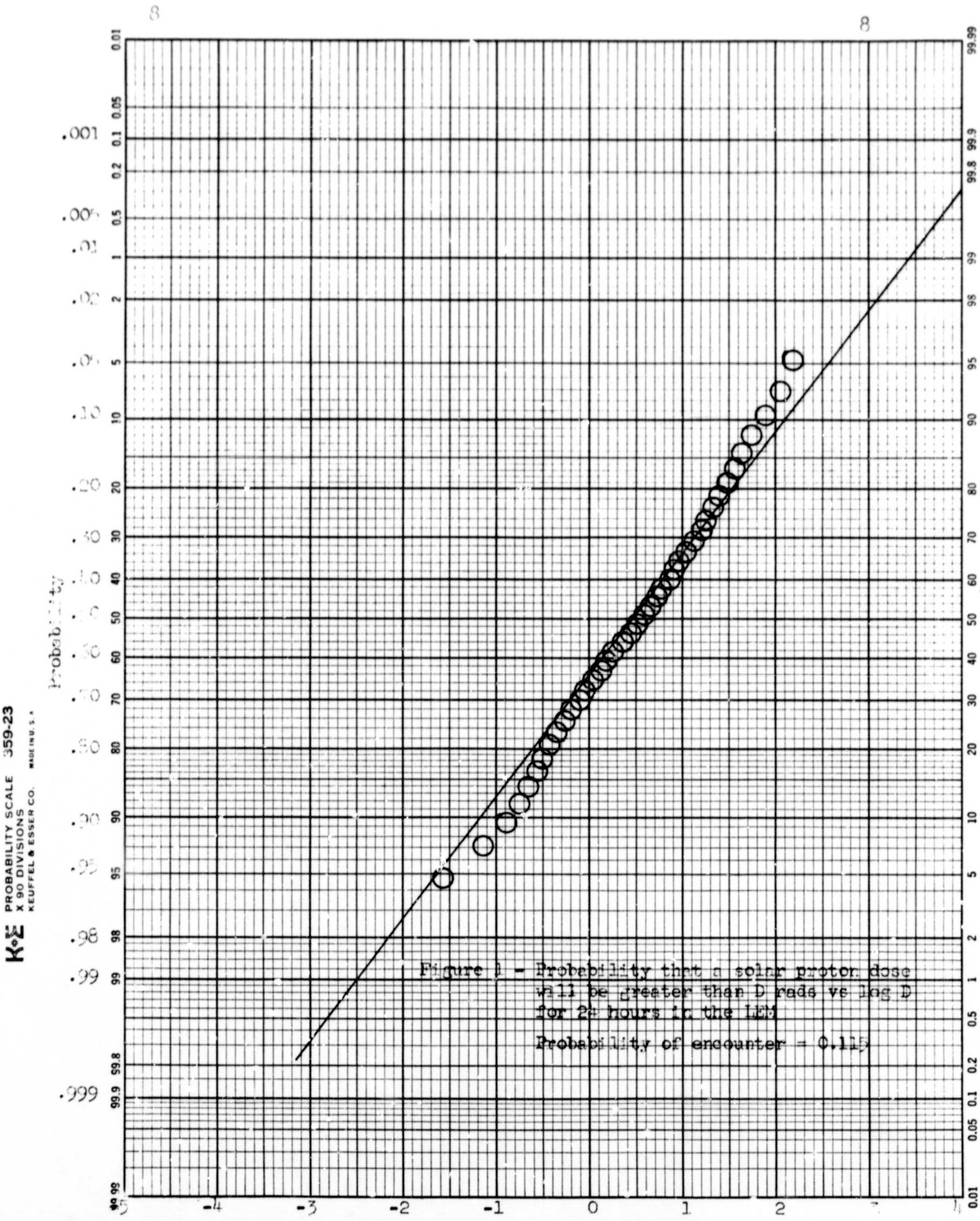

Figure 1 - Probability that a solar proton dose will be greater than D rads vs log D for 24 hours in the LEM

Probability of encounter = 0.115

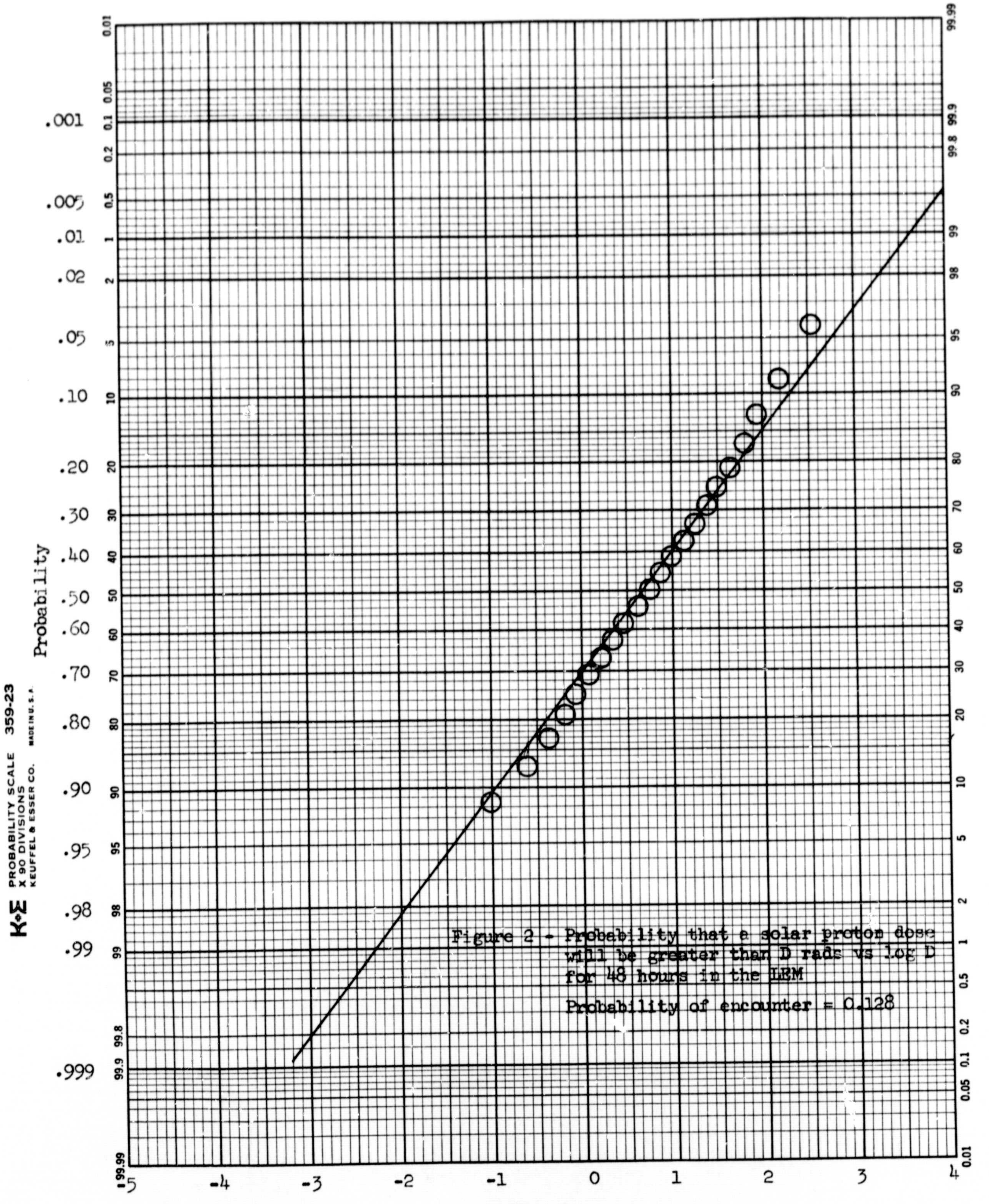

Figure 2 - Probability that a solar proton dose will be greater than D rads vs log D for 48 hours in the LEM

Probability of encounter = 0.128

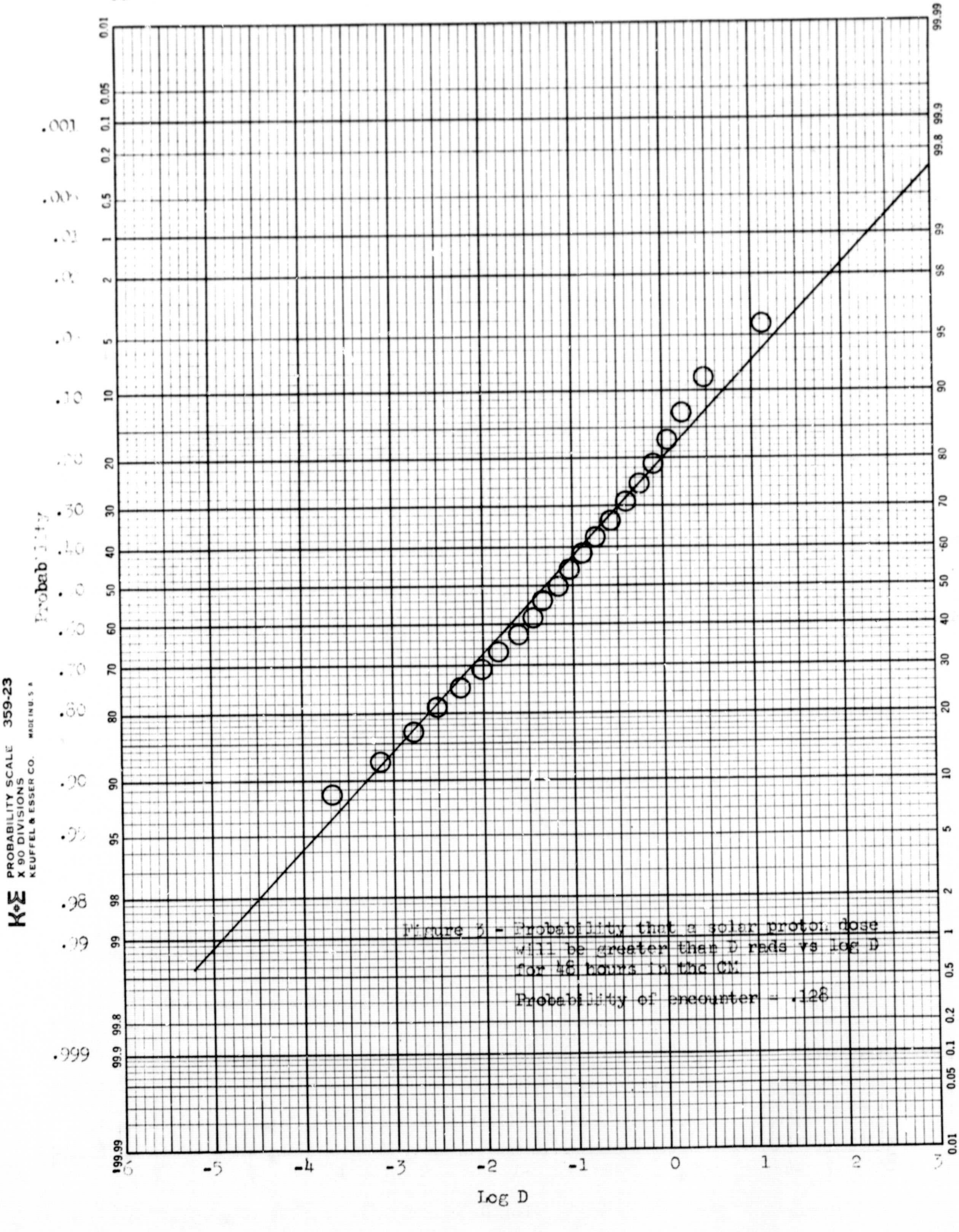

Figure 3 - Probability that a solar proton dose will be greater than D rads vs log D for 48 hours in the CM

Probability of encounter = .128

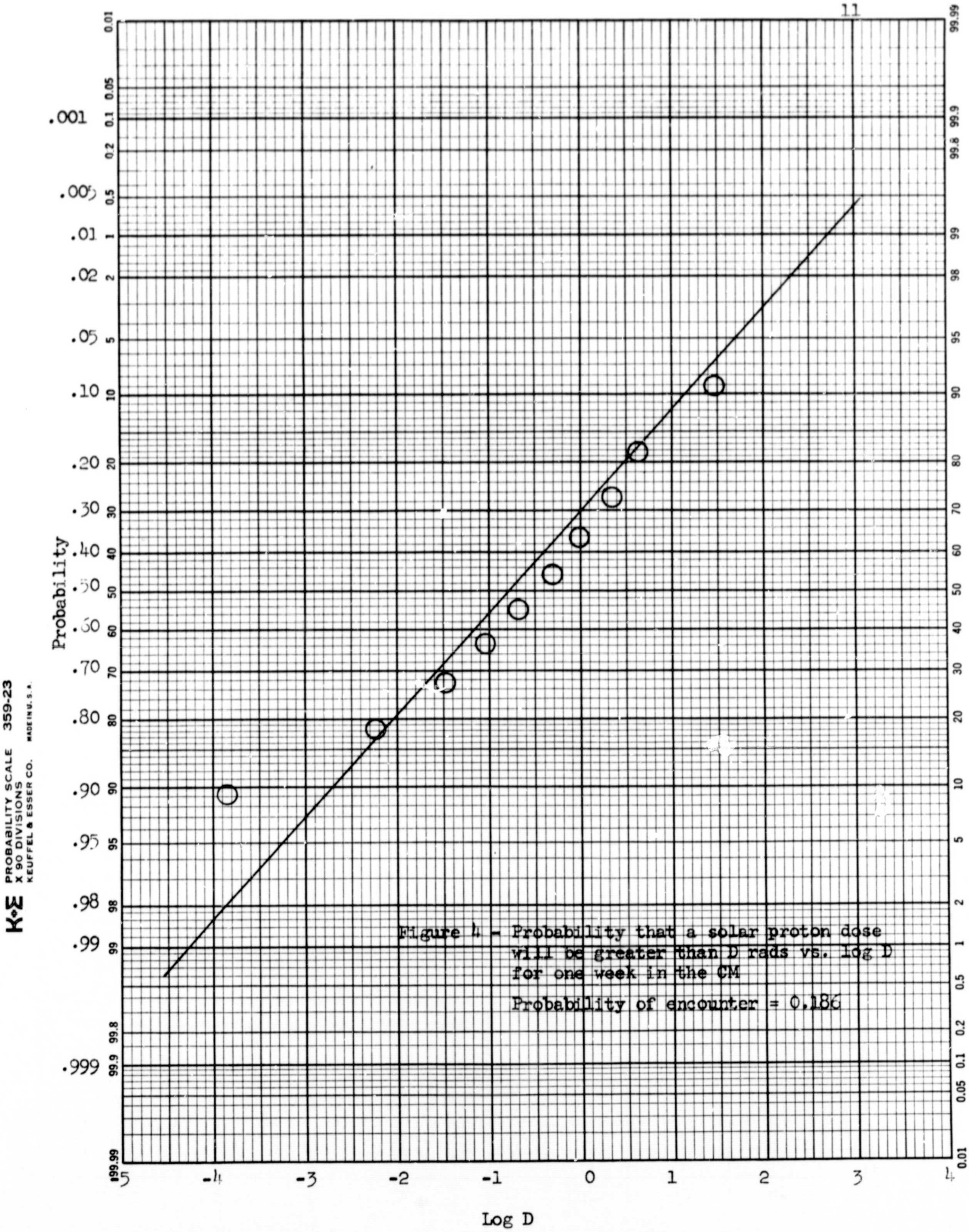

Figure 4 - Probability that a solar proton dose will be greater than D rads vs. log D for one week in the CM

Probability of encounter = 0.186

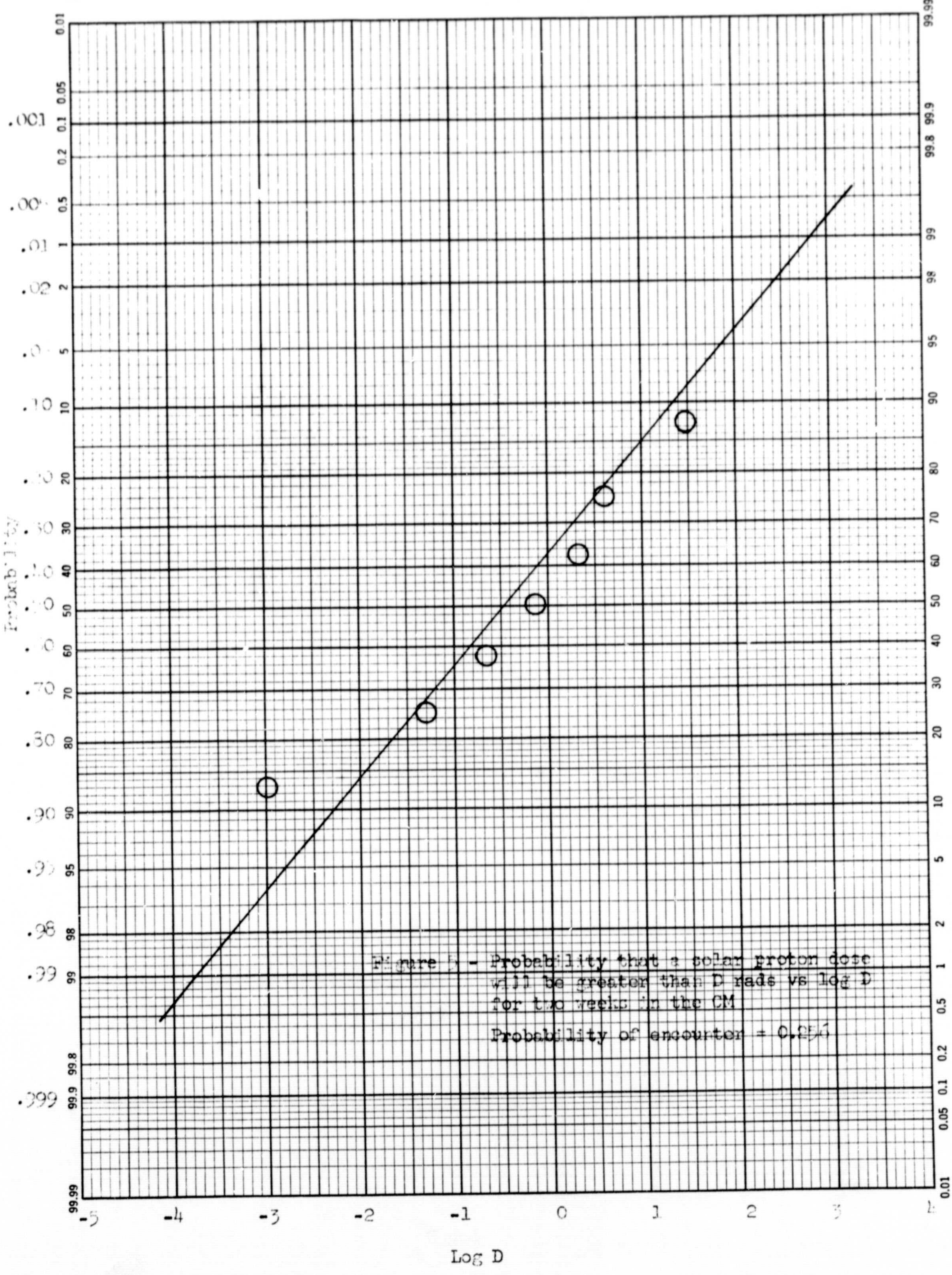

Figure 5 - Probability that a solar proton dose will be greater than D rads vs log D for two weeks in the CM

Probability of encounter = 0.256

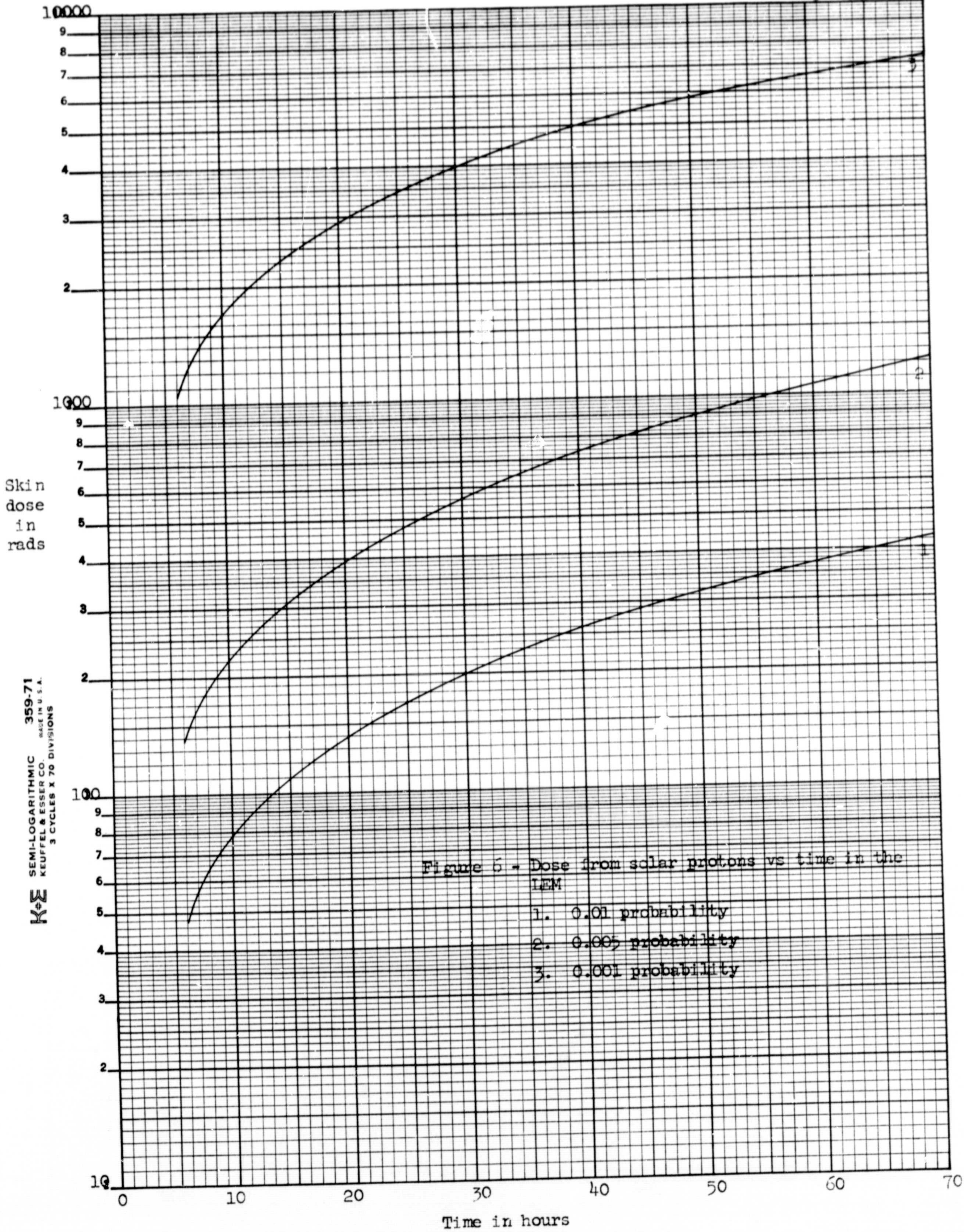

Figure 5 - Dose from solar protons vs time in the LEM

1. 0.01 probability
2. 0.005 probability
3. 0.001 probability

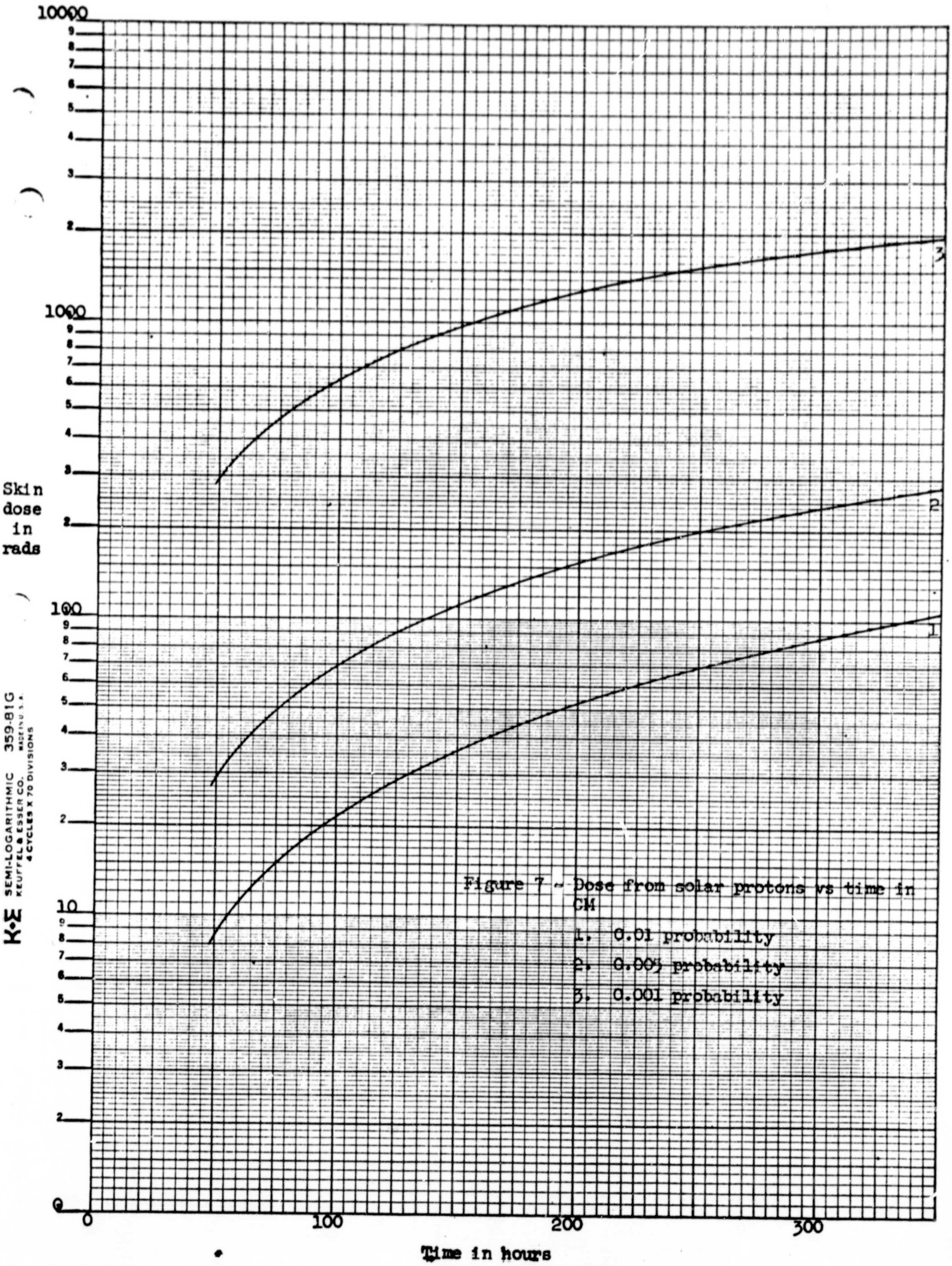

Figure 7 - Dose from solar protons vs time in GM

1. 0.01 probability
2. 0.005 probability
3. 0.001 probability